Real-time continuous monitoring: A new paradigm for transformer asset management

Caribbean utility case study reveals lessons for the global power industry

ABSTRACT

A major utility in the Caribbean discovered a fatal flaw in a transformer before it caused a costly incident. A hydrogen sensor recently installed on the transformer detected the presence of hydrogen gas in the insulating fluid. Crews were able to remove the transformer from service before a failure occurred. The article explains hydrogen sensor technology, discusses transformer reliability, and compares continuous monitoring to time-based maintenance.

KEYWORDS:

hydrogen; sensor; monitoring; maintenance; case-study

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1. Introduction - The challenge: Visibility in an era of uncertainty

In May 2024, a utility transformer operating in the Caribbean for 12 years suddenly began generating dangerous levels of hydrogen gas. The utility's current maintenance practice at the time was to take an offline sample every 12 months. Working on that schedule, the severely damaged low-side winding discovered during a later inspection could have triggered a catastrophic failure, leaving thousands of customers without power and causing millions of dollars of damage.

Fortunately, the utility recently connected the transformer to a continuous hydrogen monitor, which detected the hydrogen gassing within weeks. This detection enabled the utility to safely remove the unit from service and prevent potentially disastrous consequences.

This near-miss reveals a troubling reality facing the global power industry: the traditional approach to transformer maintenance, periodic manual testing at six to 12-month intervals, is fundamentally inadequate in an era of aging infrastructure, declining manufacturing quality, workforce shortages, and exploding energy demand.

The question utilities must confront is not whether their transformers will fail, but whether they'll see the warning signs in time to act.

This major utility, serving more than 3 million customers, faced a challenge common to power providers worldwide: obtaining up-to-date, actionable performance data for its transformer fleet. With transformers of varying ages and conditions scattered throughout its service territory, the utility relied on traditional, sporadic manual testing methods that yielded uncertain and often unreliable results. Staff sought a more uniform approach to evaluate transformer health throughout the service area and better manage these critical assets.

The utility's tropical location added another layer of complexity. Surrounded by salty ocean water, the utility needed monitoring solutions designed to withstand harsh environmental conditions that accelerate equipment degradation. Extreme weather events such as hurricanes further complicate asset management, requiring robust solutions that can survive in challenging operational environments.

2. The inadequacy of time-based maintenance

Current industry standards typically recommend transformer oil sampling at intervals of 12 to 24 months, with some utilities implementing best practices of six-month intervals for larger, more critical units. Even within that shorter six-month interval, utilities have no data and no visibility of the asset during the time between sampling.

However, faults can develop rapidly, with some progressing to failure in a matter of months. This timeline means utilities practicing annual or even semi-annual testing are essentially relying on chance, potentially missing critical deterioration windows entirely.

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Beyond the timing issue, conventional DGA methods that rely on simple limits or thresholds often generate false alarms, frustrating maintenance teams and leading to unnecessary interventions. A respected research firm's reliability-based DGA (Dissolved Gas Analysis) approach addresses this by correlating fault gas production with actual transformer failures from an extensive database, providing a quantifiable Hazard Factor that indicates the rate (in percent per year) at which a transformer's risk of failure is increasing. This approach helps utilities distinguish between transformers requiring immediate attention and those that can continue operating safely, reducing false alarms while improving the detection of genuine threats.

3. The potential failure to functional failure (PF) curve and condition-based monitoring

According to CIGRE's Guide for Transformer Maintenance (the International Council on Large Electric Systems) [4], the performance-versus-time curve (figure 1) illustrates why time-based maintenance falls short. From the moment equipment is installed and energized, there exists a period before the condition begins to deteriorate, followed by a detectable degradation phase and ultimately failure. In time-based maintenance programs, utilities have a high likelihood of missing both the initial deterioration point and even the stage when changes become detectable through analysis.

Continuous online monitoring fundamentally changes this equation. By monitoring from installation forward, utilities can detect initial deterioration earlier, enabling proactive intervention that effectively extends equipment life. As CIGRE notes, continuous monitoring is “a technique where we’re continuously tracking or supervising measurements, and it can form the basis for condition-based monitoring, which effectively reduces the risk of unexpected catastrophic failure.”

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4. Background: A transformer with a troubled history

The Caribbean utility’s situation illustrated these challenges. They had recently removed a transformer from service due to gassing issues. This unit, originally installed approximately ten years earlier, had not reached the end of its anticipated service lifespan, or the industry-accepted 20 to 25 years. The utility performed degassing, replaced insulating fluids, and returned the transformer to service. However, what the utility truly needed was a system providing real-time, continuous monitoring and actionable data. This allows staff to instantly evaluate the transformer’s condition, because frequent manual testing proved impractical, costly, and time-consuming. Additionally, the solution needed to be cost-effective, given budget constraints common to many utilities.

5. The pilot program: H2scan GRIDSCAN® 5000

To address these issues, the utility decided to beta test the H2scan GRIDSCAN® 5000 Hydrogen Sensor on a 24 MVA, 115/13.2 kV transformer with a known history of gassing issues, making it an ideal candidate for the pilot program.

Unlike other sensing solutions, the H2scan sensor installation (figure 2) took fewer than two hours to complete without requiring an outage or power shutdown, which is a significant operational advantage. The utility was impressed with both the ease of installation and the ability to access data via the cloud.

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6. The critical detection

Less than one month after the H2scan sensor was installed on the transformer, it detected a sudden, rapid rise in hydrogen levels in the transformer. According to the IEEE DGA (Dissolved Gas Analysis) guide for mineral oil-immersed transformers (C57.104-2019) [5], a sudden, rapid rise in hydrogen levels indicates an acute fault condition requiring immediate attention.

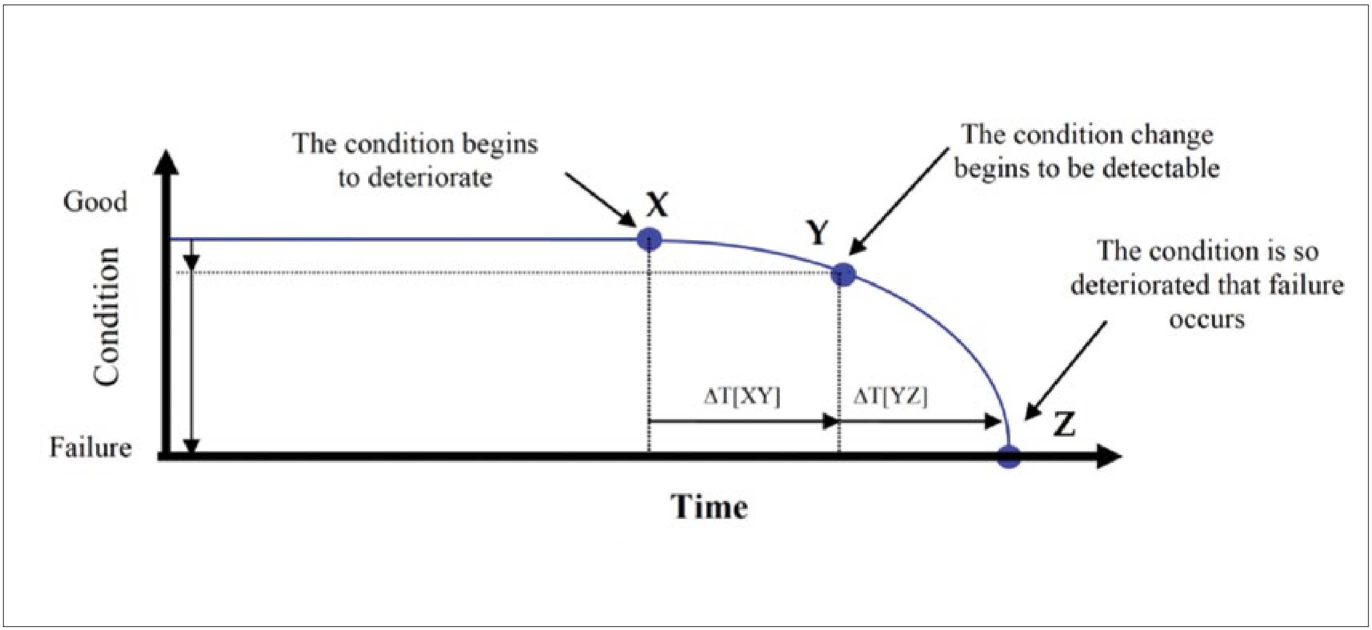

Figure 1. This chart shows theoretical transformer condition degradation. Time-based maintenance must occur at intervals frequent enough to detect insulation oil breakdown. Continuous hydrogen monitoring avoids this challenge. (Source: CIGRE 445, Guide for Transformer Maintenance, figure 2, February 2011.) [4]

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Figure 2. Installation of the continuous monitoring sensor took fewer than two hours to complete without requiring an outage or power shutdown.

Laboratory Reported Readings from Sample Data (May 2024)	ppm
Hydrogen	80
Methane	45
Ethane	15
Ethylene	103
Acetylene	52

Upon receiving this information, the utility pulled a manual sample for laboratory testing. The lab results confirmed 80 parts per million (ppm) of hydrogen and 52 ppm of acetylene in the sample, closely matching the H2scan sensor's reading of 82-83 ppm of hydrogen. This correlation validated the sensor's accuracy and provided confidence in the real-time monitoring approach.

7. The response: Preventing catastrophe

After receiving this lab confirmation, the utility took immediate action. They de-energized the transformer and requested that the manufacturer inspect the unit. During this inspection, the team discovered severe damage to the low-side winding. Based on these findings, the utility decided to permanently remove the unit from service and seek a replacement.

The early detection prevented what could have been a catastrophic failure with significant consequences, including:

- Extended power outages affecting thousands of customers
- Safety risks to utility workers and the public
- Environmental contamination from oil spills
- Substantial replacement costs potentially exceeding budgeted maintenance expenses
- Cascading grid impacts

The utility was able to leverage sensor data as a life extension and service determination tool, enabling proactive measures to protect infrastructure, and with no power disruption to provide reliable customer service.

Units built during the 1960s and 1970s boom period in North America, for example, were particularly durable, since they were constructed prior to the era of CAD

8. Industry-wide implications: The quality challenge

This case study illuminates broader trends affecting the global power industry. The past few decades have witnessed a difference in transformer manufacturing, with transformers from 20 years ago, for example, constructed in a more robust manner than today. One significant factor is computer-aided design (CAD). Units built during the 1960s and 1970s boom period in North America, for example, were particularly durable, since they were constructed prior to the era of CAD. Engineers built units with substantial safety margins, such as extra insulating paper, additional oil volume, and oversized components in some cases. The standard industry specification for these transformers was 20-30 years; however, the actual service life of these sturdy units is closer to 40-80-plus years.

Modern manufacturing practices, enabled by CAD, have eliminated these traditional buffers. For example, according to TJH2B, a testing laboratory, since 1960, the oil volume per MVA of transformer capacity has been reduced by 66%. [6] This reduction correlates with decreased paper insulation, tighter clearances, and smaller footprints—all factors that affect transformer operation, construction tolerances, and maintenance requirements. Ironically, this means that modern transformers designed for 25-40 years may struggle to reach their design life due to tighter margins and increased stresses.

Several factors drive these changes:

Manufacturing economics: Transformer costs have risen dramatically, approximately 65% since 2020 alone, and more than 435% during the past 40 years, according to Federal Reserve Economic Data [7]. Competitive pressures push manufacturers toward leaner designs that meet specifications with minimal material usage.

New market entrants: Increased equipment demand has attracted new manufacturers that may not maintain traditional quality standards, particularly regarding materials selection and construction techniques.

In the US alone, data center consumption is expected to surge 133% from 183 TWh in 2024 to 426 TWh by 2030, placing tremendous strain on existing equipment in certain localities

Design margin reduction: Tighter tolerances leave less room for operational stresses, including overloading, environmental factors, and manufacturing variations.

Despite these quality concerns, recent data offer an encouraging counterpoint. The most recent CIGRE international transformer reliability survey (WG A2.62, 2024) [8] analyzed more than 425,000 transformer years of operation from 66 utilities in 27 countries. It found that "as a result of increased emphasis on improving reliability over the life cycle, the failure rate has now fallen by more than half since the last Working Group" in 2015. This improvement suggests that while design margins have tightened, advances in manufacturing quality control, testing standards, and maintenance practices have compensated, resulting in net reliability gains. However, the study also confirmed that "the hazard rate for scrapped units accelerated after twenty years of age," emphasizing the continued importance of monitoring equipment condition rather than relying solely on age-based replacement strategies.

9. The demand challenge: Strain on aging infrastructure

Beyond manufacturing quality, transformers face unprecedented operational stresses. The International Energy Agency projects that global data center electricity consumption will more than double from 415 terawatt-hours (TWh) in 2024 to 945 TWh by 2030 [1], with AI workloads accounting for 35-50% of that demand by decade's end. In the United States alone, data center consumption is expected to surge 133% from 183 TWh in 2024 to 426 TWh by 2030 [2]. This concentrated demand, often clustered in specific geographic regions, places tremendous strain on existing equipment in certain localities.

Growing energy demand, in part due to AI data centers and EV initiatives, places tremendous strain on existing equipment. This strain translates directly into heat generation, one of the three primary enemies of transformer operation (alongside moisture and oxygen).

H2scan technical experts point to the fact that for every 8°C increase in operating temperature, a transformer's expected lifespan is halved [9]. This dramatic relationship between heat and aging means that transformers designed a decade ago may now operate under conditions the designers never anticipated. In that instance, operators not only run the risk of that piece of equipment failing due to excessive load, but it will also create power quality issues for existing customers.

10. The workforce challenge

Compounding these technical challenges, utilities face shortages of qualified personnel to manage equipment. Experienced transformer specialists are retiring, and training new staff requires years

Continuous monitoring also has significant environmental advantages, as transformer replacement generates CO_2 from manufacturing and transportation

> **The hydrogen sensor operates reliably in temperatures from -40°C to 70°C (-40°F to 158°F), making it a practical install across diverse global climactic conditions**

of hands-on experience. There is anecdotal evidence that some utilities have ceased annual testing, operating under a “run to fail” approach born of necessity rather than choice.

Continuous monitoring technology helps address this workforce gap by providing consistent, objective data that reduces dependence on individual technician expertise while enabling more efficient deployment of available personnel to address identified issues.

11. Environmental considerations

Beyond operational and safety benefits, continuous monitoring delivers significant environmental advantages. Replacing a transformer creates substantial carbon emissions. A 1 MVA transformer replacement generates approximately 12 tons of CO_2 from manufacturing and transportation. At the utility scale, a 750 MVA transformer replacement exceeds 1,600 tons [3] of CO_2.

As energy demand increases and units fail, the industry’s carbon footprint grows unless utilities can extend existing asset life. By detecting faults early and enabling timely intervention, continuous monitoring helps reduce unnecessary replacements, supporting sustainability goals while improving reliability.

12. Technology performance in harsh environments

This utility’s use of the GRIDSCAN 5000 hydrogen sensor showcased several key benefits:

Early detection capability: Providing timely warnings before conditions escalate to catastrophic failure.

Continuous real-time data monitoring: Eliminating blind spots between manual testing intervals.

Accuracy in harsh environmental conditions: Maintaining reliable operation in corrosive saline atmospheres and extreme weather conditions. The sensor operates reliably in temperatures from -40°C to 70°C (-40°F to 158°F), making it a practical install across diverse global climactic conditions.

Cost-effectiveness: Economical pricing makes widespread deployment fleet-wide a feasible option.

Ease of deployment: Installation can be completed without outages or power interruptions with minimal labor.

Rugged reliability: IP68 rating for water and dust exposure, with a ten-year warranty on the hydrogen sensing element. No moving parts and patented auto-calibration (figure 3) eliminate drift and periodic recalibration needs, maximizing uptime.

System integration: IoT/SCADA/ADMS ready with Modbus or DNP3 connectivity for seamless integration with existing utility systems.

13. Broader impact and implementation plans

Following this successful pilot, the utility has taken significant steps:

Working with H2scan to specify sensors on new transformer purchases

Planning retrofits for existing transformers across the fleet

Addressing cybersecurity concerns and validating system safety protocols

Developing a four-to-five-year implementation plan

Initial deployment will cover approximately 80 critical units, with plans to expand potentially covering hundreds more transformers across transmission, generation, and distribution systems. This systematic approach allows the utility to prioritize the highest-risk assets while building organizational capability and confidence in the technology.

14. Global applicability

While this case study focuses on a utility in the Caribbean, the lessons apply globally. Utilities worldwide face similar challenges:

- Aging infrastructure approaching or exceeding design life
- Increasing load demands from electrification and digitalization
- Workforce constraints limiting ability to perform traditional maintenance
- Budget pressures requiring cost-effective solutions
- Environmental goals necessitating asset life extension
- Regulatory requirements for reliability and safety

Different regions follow different standards—IEEE in North America, IEC internationally, CIGRE in many countries—but all internationally recognized standards acknowledge the value of continuous monitoring. Hydrogen monitoring technology transcends regional differences, providing objective data that informs better decision-making regardless of local practice.

A new paradigm

This Caribbean utility example demonstrates that continuous online moni-

> **Systematic approach allows the utility to prioritize the highest-risk assets while building organizational capability and confidence in the technology**

Figure 3. Final installation of the H2scan GRIDSCAN® 5000 hydrogen sensor, which requires no periodic calibration. Workers should not have to return to the sensor for at least ten years, minimum.

Hydrogen monitoring technology transcends regional differences, providing objective data that informs better decision-making regardless of local practice

toring signals a fundamental shift from time-based maintenance on scheduled intervals to maintenance based on reliable, real-time, actionable data. This transformation addresses multiple challenges simultaneously: compensating for reduced manufacturing margins, managing workforce constraints, accommodating increased loads, and reducing environmental impact.

The transition from periodic manual testing to continuous automated monitoring parallels transformations in other industries. The power industry can now tap into the promise and performance that continuous visibility supplies for asset health.

For utilities evaluating their transformer management strategies, the question is no longer whether to implement continuous monitoring, but how quickly they can deploy it across an entire fleet. The technology exists, the business case is clear, and the price points make it a viable possibility for any size utility.

The successful early detection of the defective transformer validated both the technology and the approach. By preventing a potentially catastrophic failure through timely intervention, the utility protected its infrastructure, maintained reliable service, optimized maintenance resources, and demonstrated the value of investing in modern monitoring solutions. These benefits—multiplied across an entire fleet over years of operation—represent a compelling case for transformation in how the industry manages its most critical assets.

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